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# OPERATIONAL IMPACT OF PRODUCT VARIETY IN THE PROCESS INDUSTRY

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**Abstract:** *The purpose of this research article is to examine the impact of product variety on production performance in the process industry. As the number of product variants sold by a process company typically impacts the run length, production data from a mineral wool insulation manufacturer is analyzed to quantify the impact of longer runs on productivity. In testing the hypothesis that longer runs lead to higher productivity, the results show that the number of variants in itself is not a sufficient parameter to explain the variation in production performance; rather, the different types of product variants and their production sequence must also be considered. Based on the findings, a method for quantifying the production cost of product variety in the process industry is developed, adding to the literature a rich case showcasing factors which influence production performance and the impact is measured with metrics.*

**Keywords:** *Complexity, Production Performance, Process Industry*

## 1. INTRODUCTION

The plight of increasing product variety and process complexity is a reality for manufacturing companies as businesses have become more global and customers have demanded more customized products. As the level of customized products has grown, the production processes used in industry have transformed, moving from craft production in the 1800's to mass production and the early 20<sup>th</sup> century and now to mass customization in the late 20<sup>th</sup> and early 21<sup>st</sup> centuries [1]. The recent shift to mass customization has brought with it greatly increased product variety to customers, but also greater challenges to manufacturers in order to produce greater variety. While product variety should be added in a way that adds the most value to the customer, the profitability of doing so must also be considered [2]. To remain competitive, manufacturing companies in many industries must determine the appropriate amount of product variety to offer within their product range to both satisfy customer needs and keep low production costs. This first requires a firm understanding of how product variety impacts the complexity of production processes.

From an industry perspective, complexity caused by increase product variety and other factors is one of the top issues faced by companies in the process industry. A survey of managers at chemical companies and process companies revealed that 72% of managers consider complexity management one of their top priorities in running their business [3].

Offering greater product variety poses a particular challenge in the process industry where increased product variety can lead to reduce batch sizes, increased setup and changeover time, increased waste and lower productivity [4]. The costs of these inefficiencies are particularly high in the process industry due to the high cost of capital equipment in the production processes and the long changeovers required between production runs [5].

Various methods have been presented in the literature for quantifying the impact of product variety on production performance in the process industry [6], but these have been largely based on sophisticated regression techniques and optimization models. What is missing is the link between these techniques and operational rules which can be implemented easily in production and production planning departments. This article aims to bridge this gap by creating an operational procedure for calculating the impact and costs in production due to increased product variety.

To further investigate the situation for process industry companies facing increased product variety, the following research question has been developed to guide the study: *what is the impact of product variety on production performance in the process industry?*

The American Production and Inventory Control Society (APICS) defines process industries as “businesses that add value to materials by mixing, separating, forming or chemical reactions [which] may be either continuous or batch and usually require rigid process control and high capital investment” [7]. These companies produce materials such as glass, ceramics, stone, clay, steel, metal, chemicals, food, beverages, textiles, lumber, wood and pulp and paper [8]. One of the distinctive characteristics of a company in the process industry is the production of high volume products with low variety using mass production systems.

Product variety is here referred to as the number of finished end items produced. The number of finished end items has been used as a measure of product variety in various operations management studies within different business areas, including sales, production, and warehousing [6][9][10].

This paper is structured as follows: first, literature is reviewed which covers the topics of product variety and the process industry; next the methodology of mixed methods is presented followed by an analysis of the findings at the case company. To close, conclusions are presented and future work is suggested.

## 2. LITERATURE

The issue of product variety in the process industry is underexplored compared to the automotive and electronics industries, which were some of the first to adopt the strategies of mass customization [1] [11] [12] [13]. A list of selected studies of product variety on performance in the process industry includes:

- Impact on productivity and margin at a chemicals company [4],
- Impact on inventory and scheduling at a plastics company [6],
- Impact on quality, service, flexibility and dependability in batch and continuous manufacturing companies [14], and
- Impact on inventory costs at a soft drink company [9].

The level of product variety can directly impact the performance of production measured in performance indicators such as throughput, machine utilization, average run length, quality of goods produced, and changeover time [4]. Achieving a high utilization is one common objective in the process industry as maximizing output minimizes production costs per unit [5].

The work of Berry and Cooper [4] provided a method for assessing the effects of increased product variety on manufacturing performance in the process industry. In their study of chemical manufacturer, they used regression analysis to assess different factors influencing production performance in the process industry. They found that smaller batch sizes caused by increased product variety resulted in lower productivity levels for some cases at the company, however there were processes for which there was no relationship between the two measures. This leaves an open question of whether or not product variety impacts productivity.

Besides linear regression, other methods of analysis such as operations research models have been developed for studying the impact of variety on production. Cooke and Rohleder [6] adapted an economic lot sizing model for discrete processing industries to fit the unique changeover waste loss in the process industry. This study revealed that production scheduling in the process industry is a particular issue as the production runs can be very long and have a high value in terms of finished product [6].

The process industry is selected for analysis due to the limited work present in this area on quantifying the impact of product variety on process complexity in production. Orfi, et al. [15] conclude in their literature review that very little research has been performed in regard to the complexity of the product in process industries (e.g. glass, food, petroleum products). They note that interdependence level between components in these industries is higher which can affect the overall complexity within the system. There is a challenge in studying these products made in the process industry since many of the processing occurs at the molecular level, making the interactions between components difficult to visualize. Product variety has been shown to have a higher impact on costs for continuous processing companies than for flow shop and project organizations [14], thus motivating further study in this area.

As the process industry is typified by having expensive industrial processes in the production phase [5], this study will focus on the impact of complexity on production. Quantifying how much more product variety impacts costs will be the focus of this article. The impact of product variety on other areas of the supply chain is not considered since we assume that there is no impact on production performance, which is the primary focus of this article.

While methods for assessing the impact of product variety on the performance of manufacturing systems are presented in the existing literature, the methods have little testing at companies within the process industry and require further validation to ensure applicability to different production systems. Additionally, the methods present do not provide an operational way to implement the findings regarding the quantified impact of shorter runs or production sequence in operations. For example, Berry and Cooper [6] provide equations for the calculation of contribution margin impact for a given productivity level, but offer no steps for achieving and monitoring increased output.

The purpose of this paper is to examine the interaction between product variety and manufacturing performance in the process industry and add value in industry by creating an operational tool by which decision makers can review their production plans and product assortments to be more profitable.

## 3. METHODOLOGY

To answer the research question and determine the impact of product variety on production performance in the process industry, a mixed methods approach is taken which uses both quantitative and qualitative data from a case company [16]. The analysis will be primarily quantitative using descriptive statistics and regression analysis. Qualitative data acquired using semi-structured interviews with relevant employees will be used to supplement and interpret the quantitative data.

Data on production performance was gathered from the enterprise resource planning system and the manufacturing execution system at the case company while cost data was obtained from accounting databases. For the semi-structured interviews, four production planners were interviewed once each to obtain knowledge about the production sequencing at Insulation Company. Three, half hour interviews were conducted with a manufacturing data specialist in order to

understand the logic of the manufacturing execution system and correctly interpret the production data. Two, half hour interviews with finance controllers at the company were also performed to understand the cost structure in production.

The case company chosen is a manufacturer of mineral wool insulation materials, referred to as Insulation Company, with sales and production in North America, Europe and Asia. Insulation Company was chosen due to its presence in the process industry and difficulty with managing the production of an increasing product assortment. Managing product-variety and process complexity has been a focus at the company since 2011 after their number of stock keeping units (SKUs) increased noticeably in the early 2000s.

Mineral wool production is an energy intensive process involving the melting of stone, spinning of mineral wool fibers, lamination of the fibers into wool and then curing, slicing and packaging the wool into finished goods. This process is shown in Figure 1 and consists of a single process flow. The main production line is characterized as a continuous production system as the product is homogenous until the cutting step. After cutting, the product takes a discrete form in which it is packaged and sold.

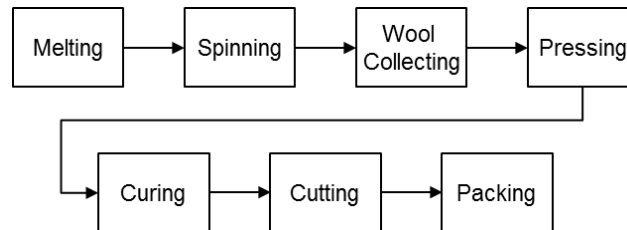


Figure 1. Mineral wool production process

### 3.1 Hypothesis

A hypothesis for this research question was developed to explore the impact of range complexity on a single measure of operational performance: process time productivity (equal to the saleable output/process time). Since producing greater variety on the same production system implies smaller batch sizes and shorter run lengths, production run length is used as an indicator of the level of product variety at the company. The hypothesis and alternative hypothesis is modeled after the third hypothesis in the work of Berry and Cooper [4] to measure the change in productivity for the process.

- H1: Production run length and process time productivity (tons saleable output/(process time)) are not related.
  - H1A: Production run length and process time productivity have a positive relationship (i.e. process time productivity increases as run length increases).

Terms relating to product variety complexity and the process industry are described below.

- Product variety – the number of unique products made on the production line.
- Changeover waste – the non-saleable product produced before a production run when transitioning from the previous production run of a different product.
- In-sequence – a term used to denote that a production run has been scheduled in the preferred sequence as detailed by the production planners at the company (e.g. products from same product family which are scheduled successively).
- Process time – (i.e. run length) the time the machine is producing both saleable product and waste product for a given production run. This does not include down time due to a production stop, missing materials, etc.

Process time productivity was selected because it serves as a direct measure of the efficiency of the production line and an indirect measure of the amount of changeover waste generated before a production run. This measure excludes the downtime experienced in a given run, thus reducing the noise in the data. Additionally, process time productivity is one of the key performance indicators used at Insulation Company which will make the findings easier to translate into practical actions and improvements in production.

### 3.2 Multiple regression analysis

To test this hypothesis, regression analysis will be applied to production data from one production line at Insulation Company in order to discern the relationships between the product variety and production performance. The production line selected for analysis is located in central Europe and it produces a level of product variety that is representative of the product portfolio at the company. The line is also currently running at full capacity and management is interested in understanding how more volume can be produced and less waste generated on this resource.

For the production line examined in this study, 1,106 production runs were selected from 2015 data for analysis (see Table 1). The runs selected represent the three major product families (PFs) made on the production line and are representative of the product mix produced on the line. Data was cleaned of the production runs with unusually high or low productivity rates due to assignable causes (i.e. a production stop, quality issues, etc.). Approximately 18% of the runs being assessed were scheduled out of the natural sequence as defined by production planners. The selected runs for each PF have varying run lengths to better calculate the impact of run length on production performance.

Reviewing the overview statistics for the runs selected, it can be seen that PF 1 has the most production runs and production volume of the three selected products. Product family 2 is produced with half the frequency of PF 1 but with one tenth the volume of PF 1 and significantly shorter run lengths. Product family 3 has the second highest volume in the runs selected, but has the lowest number of production runs and number of products. This is due to the nature of the four products in PF 3 being used as input for further processing on a different line, thus being scheduled in long runs. As the runs in PF 3 have a long run length, the planners are able to schedule them in the natural sequence more than the other PFs which are produced more frequently.

Table 1. *Production run characteristics for 3 product families assessed in one production line*

	All Runs	PF 1	PF 2	PF 3
Production runs	1,106	688	299	119
Production runs out of sequence (# and % of production runs)	902 (18%)	125 (18%)	67 (22%)	12 (10%)
Products analyzed	128	89	35	4
Production volume (% total)	40%	31%	3%	6%
Average run length (hours)	2.38	2.99	0.59	3.33

### 3.3 Model development

The regression model developed for process time productivity at Insulation Company takes the following form:

$$Y = B_0 + B_1 \ln(X_1) + B_2 X_2 \quad (1)$$

Where:

$Y$  is the process time productivity,

$X_1$  is the run length in hours and

$X_2$  is a binary variable which indicates if the production run was scheduled in or out of the natural sequence (1 indicates that the run was scheduled in the natural sequence; 0 indicates that the run was scheduled out of the natural sequence).

To create the regression model, the independent variable of primary interest, run length, was added first and tested for fit. A logarithmic fit of the run length was determined as the best representation of the data points for productivity. This was considered reasonable for productivity since there is a maximum output for a machine which the performance measurements will naturally converge to.

To further explain the variability in the data for process time productivity, other variables were added and removed using forward selection [17] in order to create a model with a parsimonious fit. Variables tested for inclusion in the model were the sequence of the product, seasonality coefficient, product density, and the process time efficiency of the previous production run. Seasonality was not included since no trend was identified in the data showing different run lengths for the high season compared to the low season. The density variable was found to be significant in initial model and with the density values being split into three distinct groups based on product family; therefore, the data set was split into three subsets in order to discern the differences between the product families.

## 4. ANALYSIS

The hypothesis stated above was tested by applying the model in equation (1) to four sets of the data: all production runs, PF 1 production runs, PF 2 production runs, and PF 3 production runs. All regressions were conducted at the 0.05 significance level. The regression results are shown in Table 2.

For the full data set, the regression results show that the coefficients for both run length and sequence are positive and significant at the 0.05 significance level. However, testing each of the PFs in isolation shows that there are different relationships for each family. For PF 1, both run length and sequence are very significant; for PF 2, neither run length nor sequence is significant; for PF 3, only sequence is significant. Since this test is meant to uncover the relationships between the variables rather than create a fixed model for the performance of a product family on a given production line, the intercept values were excluded from the table. This was also done to maintain confidentiality for Insulation Company.

Table 2. Regression results for process time productivity 3 product families

	Value	Std. Error	Significance
All products - Process time productivity (kg/hr)			
Adjusted R2	0.042		
F value/significance F	25.2		0.000*
Ln(Run length) coefficient	98.2	34.2	0.004*
In sequence coefficient	635	97.8	0.000*
PF 1 – Process time productivity (kg/hr)			
Adjusted R2	0.161		
F value/significance F	67		0.000*
Ln(Run length) coefficient	356	42.3	0.000*
In sequence coefficient	950	110	0.000*
PF 2 – Process time productivity (kg/hr)			
Adjusted R2	0.000		
F value/significance F	1.04		0.355
Ln(Run length) coefficient	137	135	0.310
In sequence coefficient	209	212	0.324
PF 3 - Process time productivity (kg/hr)			
Adjusted R2	0.081		
F value/significance F	6.21		0.003*
Ln(Run length) coefficient	139	119	0.248
In sequence coefficient	875	261	0.001*

\* Indicates significance at the 0.05 significance level

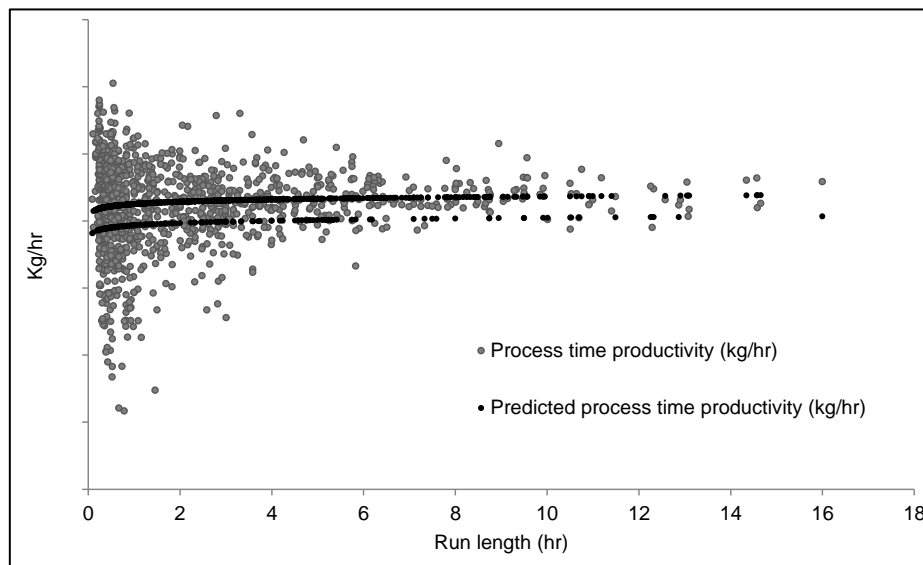


Figure 2. Process time productivity regression results for the full data set (y axis label removed for confidentiality)

A line fit plot for the regression model for all products is shown in Figure 2. The line for the predicted value of process time productivity is divided into two lines where the upper line represents the expected productivity for runs that are scheduled in the natural sequence and the lower line represents the predicted values for the runs which are out of the natural sequence. It can be seen that variability in the process time productivity of shorter runs is much higher than for longer runs.

The Adjusted R squared terms are lower than one would expect for a linear regression due to the high variation in the data, particularly for the lower run lengths under 60 minutes. Despite this variation, valuable insights can still be gained from the analysis of the statistically significant factors of run length and sequence.

The data was tested for independence and normality in line with the assumptions of linear regression [17]. The data showed deviations from normality with extreme high and low values creating heavy tails in the distribution. This can be attributed to the fact that this data was collected in an actual production environment and is subject to many factors which influence the productivity. However, the plot does appear linear in the middle of the graph indicating normality for a large set of the data. The residuals for the models, while having a slightly higher variance for low run lengths, have a mean of zero for the four tests and show no upward or downward trends.

## 5. DISCUSSION

By looking at the four p-values for the run length regression coefficients, only two of the four are below the 0.05 significance level: the coefficient for whole data set and the coefficient for the PF 1 subset of data. This leads us to reject the null hypothesis for the full data set and the PF 1 data set and fail to reject the null hypothesis for the PF 2 and PF 3 data sets.

The reasoning why the run length coefficient was only significant for one of the three PFs is not directly obvious. Two of the possible causes are inconsistencies in the data for the selected runs and the fundamental differences in the product properties between the product families. Regarding the nature of the data, the sample of runs for PF 1 is the largest of the three PFs, which could create a dominating effect on the result for the first and second regression analyses. For PF 2, the sample of runs selected for analysis were shorter than those for PF 1 and PF 3, which in turn implies that the process time productivity had greater variability. This greater variability in productivity for shorter runs makes it difficult to identify a relationship for the independent variables in the regression for PF 2. Perhaps if the runs for this product family were longer, the relationships between the two independent variables, run length and sequence, would have had a greater impact on the process time productivity, but it is not possible with the given data set.

In regards to the differences between product families, the primary product characteristic distinguishing the three families here is the product density. The interviews with the production planners revealed that changing the product density on the production line requires some of the largest changes in the equipment settings. Further comments from the planners suggested that the different PFs were scheduled with different rules of thumb to avoid reducing the output rate on certain machines. This suggests that the physical characteristics of the PFs are one of the causes for the significance or lack of significance of the run length coefficient, and thus one of the factors which determine the impact of product variety on productivity at Insulation Company.

Interesting findings were uncovered regarding the production sequence, despite the fact that it was not the primary independent variable analyzed in this study. The sequence coefficient showed to be a statistically significant factor in determining productivity in all regressions except the PF 2 regression. While the coefficient values for the natural logarithm of the run length are difficult to interpret without transforming the data, the sequence coefficients are more intuitive, representing the increase in output obtained when a production run is scheduled in the natural sequence compared to if it had been scheduled out of the natural sequence. The results from Table 2 show that productivity for PF 1 and PF 3 increases by 875-950 kilograms per hour when the production run is scheduled in the natural sequence. This was shown to be even higher in PF 1 and PF 3.

As these runs were taken from throughout the full year 2015 and were representative of the products typically made in this product family, it is reasonable to extend this quantified correlation to the whole product family.

### 5.1 Calculating the impact of product variety

Now that the relationship between product range complexity and production performance has been determined, a method for quantifying the detailed production cost of product range complexity in the process industry can be created. Using the results of the regression, Table 3 was created which shows the percentage increase in productivity achieved for PF 1 when run lengths are increased in different time increments. The percentages were calculated by taking the productivity rate for a given run length divided by the approximate maximum productivity rate obtained from the regression model (i.e. the process time productivity for a 5 hour run) and then taking the difference between the percentages for each pair of run lengths. Increasing the run length of small runs has an immediate impact on process time productivity since these runs are the most affected by changeover waste.

Table 3. *Percentage increase in process time productivity for PF 1 by increasing run length*

To run length: From run length:	0.5 hour	1 hour	1.5 hours	2 hours
0.25 hour	2%	4%	6%	6%
0.5 hour	-	2%	3%	4%
1 hour		-	1%	2%
1.5 hours			-	1%
2 hours				-

This data and knowledge of the production process were integrated into a simulation of the cost impact of increasing run lengths. First, analysis of the direct and fixed costs at Insulation Company was performed to quantify the savings from longer runs, as shown in equation (2). The equation aims to find the increased margin  $\Delta Margin$  (Euros) which results from increased revenue minus decreased costs where  $\Delta Y$  is the change in process time productivity (kg/hour),  $SP$  is the sales price (Euros/kg),  $P$  is the cost of packaging materials (Euro/kg),  $X$  is the sum of the run lengths being adjusted (hours),  $W$  is the cost saved in reduced waste processing (Euros) and  $L$  is the labor cost savings of longer run lengths (Euros).

$$\Delta Margin = \Delta Y \times (SP - P) \times X + W + L \quad (2)$$

For other companies, there may be other material costs which should be added, but this was excluded for the Insulation Company in this study since the quantity of raw materials utilized would not change with increasing run length; rather, less waste would be produced. It is also possible to add the costs of extra processing at additional stages of production according to the production system at the company. The quantification method has been created for a production line which is at full capacity with the assumption that the increased output from longer runs would create finished goods that would be sold. This is a safe assumption for the case of Insulation Company, but would need to be assessed in a case by case basis depending on the demand in each company. Also, when utilizing the equation, it should be considered that any labor cost savings due to longer runs should be translated into alternate shift schedules or layoffs.

It was not possible to fully simulate equation (2) at Insulation Company due to the lack of data on the waste processing and labor staffing level changes and the sensitivity of the revenue data. However, it was possible to quantify the effect of increasing all run lengths on the overall output of the production line using the regression output for all products. For example, consolidating all short runs (less 1 hour) for each product to an average run length of 1 hour can increase overall output by 1,1% in the same amount of production time. Increasing the same runs to a 2 hour minimum run length increased output by 1,7%. Further scenarios can be created to establish a minimum run length rule for planners to use so the company can achieve the desired level of output in a given period, thus making the analysis results actionable at the operational level.

It should be noted that this discussion takes a view of the impact of variety on production without consideration for the impact on warehousing. The results of the analysis should be used cautiously and not used to motivate endless increase of run lengths which could increase warehouse costs due to higher inventories.

These findings were synthesized into a 5-step method for the quantification and reduction of product-variety induced production cost in the process industry (see list below).

1. Identify the key factors impacting process time productivity using regression analysis.
2. Apply production cost data to quantify the change in cost based on the key factors.
3. Set a target for improvement in process productivity or production cost (applicable for production lines close to maximum utilization).
4. Create operational rules based on the factors and targets (e.g. target run lengths and sequencing for planners).
5. Track production performance to ensure results are attained and repeat steps 3 and 4 if necessary.

The first step of the framework involves applying regression analysis technique as used in this paper. This step will identify the most influential factors relating to product variety which impact production performance. The second and third steps involve applying the company cost data and setting targets based on their performance ambition level. The fourth step translates the results of the regression into operational methods for production planning and scheduling. This proposed technique is designed for a manual planning process, as was seen in Insulation Company, but can be adapted to fit automated planning systems that are built into ERP software packages. The fifth step is included to follow up on the improvement and embed the knowledge of the extra cost of product variety into work routines at the company.



## 5.2 Comparison with existing literature

Returning to the research question of the impact of product variety on production performance in the process industry, this study shows that it depends on the product characteristics and the scheduling practices of the company. A low volume product which is scheduled in the right sequence and with a sufficiently long run length could be profitable for a company to produce and not negatively impact production performance. Conversely, a high volume product that is produced in small runs and scheduled out of the appropriate production sequence can negatively affect the production performance. In the context of existing literature, this finding adds to Christopher's view that product variety should not only be added so as to increase value to the customer while minimizing internal costs [2], but should also be *scheduled* to achieve the same objectives. In this case in the process industry, the scheduling of additional products is the main lever determining whether adding an extra product will help or hurt the business [5] [6].

The findings can be seen as comparable to those of Berry and Cooper [4] who found batch size as statistically significant factor affecting the run time productivity for two processes at a chemicals company. However, they neglected to perform an analysis by product family. This study adds the idea that product characteristics (e.g. density) also have an impact on the production performance which may override the benefits of increasing run lengths and lower changeover waste for certain products. Furthermore, this work shows the applicability of the assessment method of Berry and Cooper [4] to alternative production systems such as mineral wool production in the process industry.

## 6. CONCLUSION

This study sought to assess the impact of additional product variety on production performance in the process industry and calculate the differential production cost incurred by adding product variety and reducing run lengths. The results support that a product-specific view must be taken when analyzing the production data in order to determine the impact of variety on production performance, thus extending the analysis framework of Berry and Cooper [4]. In this study, the defining product characteristic by which product families are distinguished is the density of the product. In other process industry companies, viscosity, chemical composition, or mass could be more relevant attributes to investigate.

This paper adds to the work on the operational impact of product variety by illustrating the findings from a case company in the process industry that is previously unstudied. As a case study approach is taken, it will not be possible to extrapolate the findings to all manufacturers in the process industry. The resulting analysis and method for calculating the cost impact of product variety will be relevant to industry as they will assist product managers and production managers determine the most profitable product assortment and scheduling practices to remain competitive.

As future research, the scope of this study could be expanded to incorporate the impact of product variety on secondary stages of processing after the main process is studied. As a difference in production performance was also seen between product families, a more in depth study on how product architectures and process characteristics impact performance in this industry would be an appropriate extension of this work. This study was motivated by the work of Berry and Cooper [4] and their call for researchers to apply their approach to process industry companies beyond chemical manufacturers. Now with the findings of a mineral wool company assessed, as well, it can be equally as valuable to test the method in a company in the food or beverage sector or pulp and paper products company to provide further validation.

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